The effect of environmental change on out-migration in the Brazilian Amazon rainforest[1]

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Abstract

We use nationally representative data on migration flows to analyze how environmental change affects out-migration in the Brazilian Amazon. We characterize environmental change in terms of increases in deforested area, historical trends of temperature and precipitation, and events of temperature and precipitation extremes. The empirical analysis is based on gravity models of migration, which consider simultaneously characteristics of origins and destinations as determinants of migration flows. We find evidence that out-migration is positively affected by deforestation and long-term changes in temperature, environmental variables that presented the most remarkable change in the region. Finally, we discuss how environmental change is important to understand population dynamics in the Amazon, although regional inequalities still play a central role.

Key words

Migration, rural development, gravity model, deforestation, climate change

Introduction

The way in which expected environmental change may affect migration flows is a topic of growing debate (Opitz Sapleton, Nadin, Watson, & Kellett, 2017). Declines in agricultural productivity related to climate change and land use change choices are expected to increase the likelihood of rural out-migration (Massey, Axinn, & Ghimire, 2010). Migration can also be driven by the search for more pleasant climatic amenities (Maza, Gutiérrez-Portilla, Hierro, & Villaverde, 2019), especially in regions that already face extreme conditions of temperature and precipitation. In this article, we analyze how environmental change affects out-migration from the Brazilian Amazon based on a gravity model methodology applied to nationally representative data on migration flows.

The relation between environmental change and migration has attracted a growing interest in the socioeconomic literature, greatly due to increased environmental change awareness and its perceived impacts (Bardsley & Hugo, 2010; Kuhn, 2015). For example, Backhaus (2015) suggested that increases in average temperature and precipitation in sending countries are positively associated with emigration to OECD countries. In turn, Gray (2009) suggested that environmental change, measured by fluctuation in harvest levels, was a significant driver of internal migration in Ecuador, but not international migration.

Most studies on environmental change and migration are performed at the household-level (Backhaus, 2015). In this article, we take advantage of municipal-level socio-economic and climate data made available officially by the Brazilian government to assess how environmental change might affect migration flows in and out of Brazil's Amazon region. This is a unique case to analyze, because Brazil presents the largest population living in the Amazon region -- nearly 17 million people in 2010 (IBGE). Extreme climate conditions, generally hot and humid, with little temperature variation, undermines the quality of life and is an important vector of infectious diseases in the region. Environmental changes, such as widespread deforestation and increasing temperatures, may also introduce new diseases and make old ones out of control (Confalonieri, 2000). Moreover, basic economic activities in the region, such as the extraction of natural resources and subsistence agriculture, tend to be directly affected by increasing deforestation and climate variability. The region has warmed approximately 1°C over the last 60 years, and total deforestation is almost 20% of the original forested area (Nobre et al., 2016). Despite of that, most of the research looking at the relationship between environmental change and migration for the region assesses migration as one of the drivers of deforestation, especially with the intensive settlement process since the 1960s.

We characterize environmental change in terms of increases in deforested area, historical trends of temperature and precipitation, and extreme temperature and precipitation events. The first part of this paper describes the short and long-term trends of environmental change in the Brazilian Amazon, as well the evidences of the relationship between environmental change and migration. The second part presents our results for the relationship between environmental change and migration flows in the Brazilian Amazon. We base our empirical analysis on gravity models of migration, which consider characteristics of origins and destinations as determinants of migration flows (for example, Karemera, Oguledo, and Davis 2000). We use the finest level of geographical disaggregation for socioeconomic analysis that is available for Brazil: 756 municipalities in the Amazon region.

The first main contribution of our analysis relative to the existing literature is the focus on nationally-representative aggregate impacts, rather than micro-level household effects (Gray, 2009; Koubi, Spilker, Schaffer, & Bernauer, 2016). Since environmental change does not affect all groups to the same extent and social groups do not respond in the same way to environmental change, our central focus is on the aggregate impacts on migration flows and its implications for regional development in the Brazilian Amazon. The second main contribution is that we identify the impacts of both short and long-term environmental change on migration flows. Long-term changes include historical trends of deforestation, temperature and precipitation. Short-term changes include extreme (unexpected) temperature and precipitation events. Short-term changes may generate severe impacts or shocks on agricultural activities and social life, leaving, in some cases, local residents with no choice but to migrate. Long-term changes may generate permanent and increasing costs of adaptation and mitigation, affecting the long-term household's strategies to reduce risks and minimize costs. The magnitude of each impact will probably depend on the changes observed in precipitation and temperature levels, as well the main drivers of out-migration in the region.

Population and environmental change: the case of the Brazilian Amazon

The relationship between environmental change and migration flows in the Amazon region in Brazil has been mostly assessed from the perspective of migration as a driver of deforestation. Few studies have explored deforestation and climate change as "push factors" of migration in the region (de Sherbinin et al., 2008; VanWey, Guedes, & D'Antona, 2012).

The Brazilian Amazon provides a unique case to analyze the impacts of short-term climatic events and long-term environmental trends on migration. The most documented long-term trend in the region is the deforestation of the tropical rainforest. The Brazilian Amazon has been experiencing high rates of deforestation for many years, even though they have presented a downward trend after 2004 (Figure 1). Between 2000 and 2015, 240 thousand Km^2 were deforested in the Brazilian Amazon, an area that is equivalent to the whole United Kingdom. In 2010, the total deforested area reached 770 thousand Km^2, which represents 15% of the whole Brazilian Amazon.

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< *Insert Figure 1 – Annual and total deforestation, Brazilian Amazon* >

The deforestation of the Amazon forest has been a result of the socioeconomic dynamics in the region. Until the 1980s, a series of settlements attracted a large number of smallholder rural farmers from the poorest Northeast and South regions of Brazil (Perz, 2000). About 50 years after Operation Amazonia, spurring a series of public and private initiatives that has led to the most recent phase of development of the Amazon region in Brazil, migration was been elected as one of the main factors resulting in the deforestation and degradation of the Amazon rainforest (Andersen, Granger, Reis, Winhold, & Wunder, 2002). But the sharp process of agricultural modernization that took place in the 1990s and 2000s drastically reduced the demand for rural migrants. Nowadays, the process of deforestation has been mainly determined by the expansion of the cattle and soy industries practiced in large farms in the Amazon basin (Soares-Filho et al., 2006). Consequently, as of late, migration flows in the Brazilian Amazon is largely characterized by the rural-urban shift of population. Nearly three thirds of the population in the region currently live in urban areas (IBGE). The region also presents one of the highest rates of internal migration in Brazil: roughly 10% of the population migrated in the previous 5 years.

< *Insert Map 1 – Land use, Brazilian Amazon* >

The way deforestation and climate change have affected local communities and migration flows in the Amazon is not yet clearly understood. Increased emissions of greenhouse gases caused by deforestation of the Amazon forest has the potential to increase air temperature and cause complex changes in precipitation regimes of the region (Nobre et al., 2016). The average temperature in the Brazilian Amazon grew significantly between 1961 and 2015: 0.028°C per month. For example, the mean value of average temperatures in the 1960s was 24.4°C, it increased to 25.4°C in the 1980s and 26.4°C in the 2010s. However, there is no evidence that temperature became more volatile: the standard deviation of the monthly values reduced from 1.1 °C in the 1960s to 0.79 °C in the 2010s.

< *Insert Figure 2 – Monthly averages of temperature and precipitation, Brazilian Amazon* >

The region suffered a strong drought in the 1960s, when the annual precipitation fell to 1,500mm (15% lower than the historical average). Since then, the annual precipitation ranged between 1,800 mm (in the 1970s, 1990s and 2010s) and 1,900 mm (in the 1980s and 2000s). But the precipitation regime became more volatile: the standard deviation of the monthly values of precipitation increased from 61 mm in the 1960s to 90 mm in the 2000s, and to 82 mm in the 2010s.

Given the information presented above, we can point two main hypotheses linking environmental changes to migration flows in the Brazilian Amazon. The first one is that environmental changes bring changes in the socioeconomic structure that indirectly affect migration. For example, deforestation has several socioeconomic consequences, through enhanced drying of the forest floor, increased frequency of fires, and lowered agricultural productivity (Foley et al., 2007; Hatfield & Prueger, 2015). The loss of forests can also degrade key ecosystem services, such as carbon storage in biomass and soils, the regulation of water balance and river flow, and the modulation of regional climate patterns. In this respect deforestation and climate change have the potential to directly affect economic activities, and, indirectly, migration flows in the Amazon region.

The second hypothesis is that environmental changes affect the quality of life that retain natives in their origins. Pleasant climatic conditions have shown to have decisive impacts on migration decisions (Maza et al., 2019). These authors also highlight that climatic amenities are more appealing to natives rather than to newcomers. In the Brazilian Amazon, small changes in the climate variables may have severe impacts on the quality of life of the population that already faces extreme levels of temperature, humidity and incidence of tropical diseases (Confalonieri, 2000). The incidence of Dengue fever, for example, has been related to changes in the levels of temperature and river stage (Duarte, Diaz-Quijano, Batista, & Giatti, 2019; Rosa-Freitas, Schreiber, Tsouris, Weimann, & Luitgards-Moura, 2006).

Material and Methods

Empirical Strategy

Our analyses are based on gravity models of migration, which assume that the spatial distribution of migrants is determined by gravity forces conditional on the size and characteristics of the economy and population in origin and destination (Greenwood, 1997). The models may also include socioeconomic, demographic, and environmental characteristics in order to account for the full range of factors affecting migration flows in each region (Garcia, Pindolia, Lopiano, & Tatem, 2015; Karemera et al., 2000; Kim & Cohen, 2010). Generically, our gravity model of migration can be represented by the log-linear stochastic function:

$$ln(F_{ij}) = \boldsymbol{s}_i'\boldsymbol{\alpha}_1 + \boldsymbol{d}_j'\boldsymbol{\alpha}_2 + \boldsymbol{r}_{ij}'\boldsymbol{\alpha}_3 + e_{ij} \qquad (1)$$

where F_{ij} is the migration flow from origin i and destination j, the variables in vector **s** are the characteristics in origin i, the variables in vector **d** are the characteristics in destination j, and the variables in vector **r** are factors aiding or restricting migration between origin i and destination j (distance, for example). The whole set of explanatory variables used in vectors **s, d** and **r** are presented in Table 2 and described in the next section. The coefficients in vectors $\boldsymbol{\alpha_1}$, $\boldsymbol{\alpha_2}$, and $\boldsymbol{\alpha_3}$represent the variation in $\ln(F)$ due to marginal variations in the characteristics in **s**, **d**, or **r**, respectively. The errors e_{ij} represent independent unobservable factors with constant variance across individuals i and j.

A main problem with the specification of Equation 1 is the excess of zeros flows ($F_{ij} = 0$). In our sample, roughly 99% of the pairs of origin and destination presented zero flows. In such case, applying OLS (Ordinary Least Squares) only for observations where $F > 0$ will not always consistently estimate the model parameters (Wooldridge, 2003, p. 542). Additionally, most zeros in the data may result from a different process than that of the remaining counts. This means that the lack of migration flow between some pairs of localities may be a result of a lack of socioeconomic ties (in which case the migration flow is identically zero), rather than a result of observed characteristics controlled by the gravity model (in which case the probability of flow is different from zero).

We used zero-inflated negative binomial (ZINB) models to deal with the excess of zeros in migration flows. ZINB models assume that the population is formed by two different groups (Cameron & Trivedi, 1998): a group of localities with no migratory flows, and a group of localities with randomly distributed migratory flows, which might also contain zeroes. The ZINB model also considers that the count variable has an incidence of zeroes greater than expected for the underlying probability distribution of count values. The probability distribution of the ZINB for the dependent variable F_{ij} will be given by:

$$\Pr[F_{ij}] = \begin{cases} \omega_{ij} + (1-\omega_{ij})(1+k\lambda_{ij})^{-1/k} & \text{for } F_{ij} = 0 \\ (1-\omega_{ij})\frac{\Gamma(F_{ij}+1/k)}{\Gamma(F_{ij}+1)\Gamma(1/k)}\frac{(k\lambda_{ij})^{F_{ij}}}{(1+k\lambda_{ij})^{F_{ij}+1/k}} & \text{for } F_{ij} = 1,2,\ldots \end{cases} \quad (2)$$

where Γ is the gamma function; λ is the underlying distribution mean; ω represents the probability of zero counts in excess of the frequency predicted by the negative binomial distribution and is also called zero-inflation probability; and k is the negative binomial dispersion parameter. The larger the value of k, the larger the degree of overdispersion in the data (Cameron & Trivedi, 1998). Our main interest is to model λ as a function of characteristics in origin and destination, which will be given by:

$$ln(\lambda_{ij}) = \boldsymbol{s}'_i\boldsymbol{\alpha}_1 + \boldsymbol{d}'_j\boldsymbol{\alpha}_2 + \boldsymbol{r}'_{ij}\boldsymbol{\alpha}_3 + e_{ij} \quad (3)$$

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Data source and variables of interest

Migratory flows

We defined the Brazilian Amazon by the territory of the 756 municipalities located in the official area of the *Amazônia Legal* (or Legal Amazon, in English). The *Amazônia Legal* was created by the Brazilian government in 1953 and currently encompasses a total extension of approximately 5,020,000 km² (Map 1) (Instituto Brasileiro de Geografia e Estatística, 2018).

The source of socioeconomic data for this study is the samples of the Demographic Census 2000 and 2010, provided by the *Instituto Brasileiro de Geografia e Estatística* (IBGE). We defined as migrants those who declared not to reside in the same municipality during the 5 years preceding the survey. For each one of the 756 municipalities of origin in the Amazon ($i = 1 \ldots 756$), we computed the total flow of migrants F_{ij} for each one of the 5,507 municipalities of destination ($j = 1 \ldots 5{,}507$) in Brazil between 2005 and 2010. In other words, we had a combination of $4{,}162{,}536$ ($= 756 \times [5507 - 1]$) pairs of migration flows from municipalities of origin in the Amazon to municipalities of destination in the whole Brazilian territory.

We disaggregated the migratory flows according to the urban/rural classification of the locality of origin and destination. Based on Veiga (2007), we defined a municipality as a rural locality when three criteria were met: i) the municipality was not located in any of the 35 metropolitan areas defined by the IBGE; ii) the municipality had a population size in 2010 of lower than 50,000; iii) the municipality had a population density in 2010 of lower than 80 inhabitants per km.[2] According to this typology, 3,470 municipalities (63% of the total) were classified as rural in Brazil, and the rest 2,037 (37% of the total) were classified as urban.

Between 2005 and 2010, 1.5 million migrants (8.6% of the total population) left their municipality of origin in the Amazon region (Table 1). Most of them (1,077 thousands) migrated from an urban to another urban municipality (urban-urban migration). But the number of rural out-migrants is also meaningful: 129 rural-rural and 298 thousand rural-urban migrants. Rural out-migrants in the Amazon region may be specially affected by environmental changes, once they rely more on natural resources for subsistence and income-generating activities. But there was no information about prior labor experience available in the Demographic Census.

We also classified the migratory flows into intra-regional or inter-regional migration. Intra-regional migrants are those who moved to a destination inside the Amazon region, and inter-regional migrants are those who moved to a destination outside the Amazon. Intra-regional migration largely prevails in the Amazon; 1.2 million migrants (78% of the total number of out-migrants) remained in the region.

Control variables

Control variables obtained from the Demographic Census are population size, per capita income, employment to population ratio, and the share of agricultural workers (Table 2). We used the pre-determined values of these variables ($t-1$) to avoid simultaneous causality between migration flows and socioeconomic characteristics. The lag values were computed by averaging the values between the Demographic Censuses of 2000 and 2010.

Population size and per capita income are proxies for the gravitational forces affecting migration flows. Migration flows are expected to increase with the size of the differences between average incomes in origin and destination (Borjas, 1987; Yap, 1977). Individuals are also sensitive to the risks related to their chances of obtaining employment (Harris & Todaro, 1970), which is measured by the employment to population ratio. In turn, the share of agricultural workers is a proxy for the level of occupational development and social inequalities (Maia & Sakamoto, 2015). We also considered the distance between origin and destination, which is an standard representation for the barriers and potential costs of migration (Garcia et al., 2015).

We also controlled unobservable regional heterogeneities by fixed effects using dummy variables for the 7 federal units (FUs) representing the localities of origin (Brazilian Amazon) and for the 27 FUs representing the localities of destination (whole Brazil). The use of state fixed effects mitigates potential endogeneity bias due to the correlation between unobservable regional effects and the gravitational forces of migration. For example, the level of institutional and economic development in origin and destination, which may affect both average income and migration flows.

Environmental change

The explanatory variables of interest represented the push forces exerted by environmental change in the localities of origin: variation is the deforested area, long-term trends of temperature and precipitation, short-term events of temperature and precipitation extremes.

Land-use change data are provided by project PRODES, run by the Brazilian Institute of Spatial Research (INPE). PRODES provides municipality-level land-use information in the Legal Amazon between 2000 and 2016. We computed, for each municipality, the total variation in the share of deforested area between 2000 and 2005, which represents the land-change observed before the migratory flow took place (2005-2010). This strategy is robust to reverse causality between out-migration and deforestation, although this source of endogeneity was not confirmed in prior studies (Gray & Bilsborrow, 2014). Between 2000 and 2005, deforestation in the Brazilian Amazon increased, on average, over 7 percentage points of the municipalities' total areas (Table 2). In some cases, deforestation in the period reached almost the total municipal area.

Historical climatic data were obtained from conventional weather stations of the National Meteorological Institute (INMET) and the National Water Agency (ANA). Variables originally comprised daily data of average temperature and total precipitation between the years 2000 and 2010. Daily data were interpolated through the 756 municipalities located in the Legal Amazon. The interpolation was performed by the Inverse Distance Weighting (IDW) method, which is based on the weighted linear combination of the data collected in each meteorological station, using the inverse of the distance as a weighting factor (Kurtzman & Kadmon, 1999).

After interpolation, we computed for each municipality the average monthly growth rates of temperature and precipitation between 2000 and 2010. The monthly growth rate β was estimated using the linear trend model:

$$C_t = \alpha + \beta t + s_t + u_t \qquad (4)$$

Where C_t is the climatic variable (temperature or precipitation) in month t, α the initial expected value at $t = 0$ (intercept), s_t is the seasonality, and u_t is the random error. This linear trend model was adjusted separately for each municipality using the method of ordinary least squares (OLS). We controlled seasonality s_t using fixed effects with monthly dummies.

We also computed extreme climate events, proxied by the number of months in the period 2000-2010 with average climate value (temperature or precipitation) bellow or above the historical threshold. These variables have been shown to have important impacts on agricultural production in Brazil (Maia, Miyamoto, & Garcia, 2018). The number of months representing extreme events of low (M_-) and high (M_+) climatic conditions were given by:

$$M_- = \sum_{t=0}^{T}[C_t < (\hat{C}_t - 2\hat{\sigma}_{\hat{C}_t})] \qquad (5)$$

$$M_+ = \sum_{t=0}^{T}[C_t > (\hat{C}_t + 2\hat{\sigma}_{\hat{C}_t})] \qquad (6)$$

Where $\hat{C}_t$ is the OLS estimate of the expected value of C_t and $\hat{\sigma}_{\hat{C}_t}$ is the OLS estimate of the standard error of $\hat{C}_t$.

Table 2 presents descriptive statistics for the climate variables. Between 2000 and 2010, average municipal temperatures grew by 0.003°C per month (or 0.033°C per year, which means 0.1% of the historical average temperature in the period - 26.1°C), but in some municipalities the growth reached 0.009°C per month (0.107°C per year). Extreme events of temperature in the decade occurred on an average of 2.5 (low temperature) and 2.3 (high temperature) months per municipality. The linear trend of precipitation growth in the same period was less meaningful than that the temperature growth, 0.008 mm per month (or 0.100 mm per year, which represents only 0.01% of the historical average annual precipitation in the period – 1,887 mm). But extreme precipitation events above the historical threshold were more frequent than the temperature ones: 4.4 months per municipality for the 10 years time period.

Results

The impacts on total out-migration

Table 3 presents the ZINB estimates of the gravity model of migration for all migratory flows having origin in the Brazilian Amazon (equations 2 and 3). The final sample comprised 4,101,225 observations (pairs of municipalities), since 61,311 observations (1.5% of the total 4,162,225 observations) were lost due to lack of information for the explanatory variable *deforestation*. As assumed by the ZINB model, most pairs of municipalities presented zero flows (4,062,070 or 99% of the total number of pairs). Moreover, the significant estimate for the overdispersion coefficient (k) suggests that the ZINB model is preferred to other zero inflated specifications.

< *Insert Table 3 – Estimates of the ZINB model for out-migration, Brazilian Amazon* >

The estimates for the environmental variables indicated that changes in deforestation and temperature had the most significant impacts on out-migration. The number of out-migrants increased by 0.22% for each 1 percentage point variation in the deforestation rate, holding constant other variables. At the same time, the number of out-migrants increased by 8.2% ($e^{7.922/100} - 1$) for each 0.01ºC increase in the average monthly temperature.

Extreme events of high temperature ($Temperature\ Extreme +$) had no significant impact on out-migration, whereas extreme events of low temperature ($Temperature\ Extreme -$) seemed to retain people in their Amazon origins. The number of out-migrants decreased by 2.3% for each additional month with average temperature bellow the expected trend.

Our gravity model of migration results also offered important elements to understand the socioeconomic determinants of out-migration from the Legal Amazon. Population size and distance presented the expected results: migration increased with population size in origin and destination, and decreased sharply with distance. The main push factor of out-migration was better opportunities of employment in localities of destination, proxied by per capita income and the employment to population ratio. In turn, the prevalence of agricultural activities in localities of origin is the main socioeconomic push factor stimulating the flow of out-migrants.

The impacts according to the types of migration

Table 4 presents the ZINB estimates of the gravity model segmented by the urban/rural classification of origins and destinations of migrants. Results highlighted that environmental changes tended to cause larger impact when migration takes place between urban municipalities. The impacts of deforestation and precipitation growth were larger and significant at 5% in the context of urban-urban migration: the number of urban out-migrants increased by 0.30% for each percentage point increase in the percentage of deforested area; and increased by 0.10% for each 1 mm increase in the monthly precipitation.

< Insert Table 4 – Estimates of the ZINB model for urban and rural out-migration, Brazilian Amazon >

Long-term increases in the average temperature also affected positively the flow of rural out-migrants. But, in this case, the impact was only significant in the context of urban-rural migration: the number of out-migrants increased by 0.25% for each 0.01ºC monthly increase in the average temperature. This result suggests that gradual increases in the average temperature may stimulate urban residents to search for places where weather conditions are more comfortable in rural localities. In line with this results, extreme events of low temperature in urban areas tended to reduce the flow of out-migrants.

Finally, Table 5 presents the ZINB estimates of the gravity model segmented by intra- and inter-regional migration. Results highlighted that long-term environmental changes tended to generate larger impact on inter-regional migration (from Amazon to other regions in Brazil). However, short-term extreme events of low temperature tended to reduce both types of flows.

< Insert Table 5 – Estimates of the ZINB model for intra- and inter-regional migration, Brazilian Amazon >

Discussion

Our study examines the impacts of environmental change on out-migration in the Brazilian Amazon region. Analyses are based on gravity models of migration, which consider simultaneously the push and pull macro determinants of migration flows. We find evidence that out-migration is mainly affected by changes in the land use of sending localities, namely deforestation. Long-term changes in the temperature also have positive impacts on out-migration. However, migration is not strongly affected by short-term temperature extremes or changes in the precipitation regimes.

It is difficult to untangle the complex interrelations between deforestation of the Amazon rainforest, climate change and human population dynamics. The fact is that deforestation has been the main factor responsible for greenhouse gas emissions in Brazil, contributing to climate change (Nobre et al., 2016). Deforestation and climate change may also have detrimental impacts on the quality of life, especially in a tropical region with high levels of temperature and precipitation. Moreover, both land use and climate change have direct impacts on the main economic activities in the Amazon region: cropping and grazing. For example, increases in temperature may affect the soil water evaporation and the rate of plant development (Hatfield & Prueger, 2015).

The main environmental drivers of out-migration in the Brazilian Amazon are long-term changes in deforestation and average temperature, which may probably be correlated events. Not surprisingly, these variables also presented the most remarkable increases in the region. In response to environmental change, farmers may mitigate, for example, reducing deforestation, or adapt, for example adopting agricultural innovations or shifting their activities, mainly to cattle grazing. Those that are not able to mitigate or adapt, may be forced to migrate.

Nonetheless, environmental changes have larger impacts on migration taking place from urban localities and on inter-regional migration. This result may be in consonance with the idea that environmental change affects the quality of life that retain natives in their origins (Maza et al., 2019). Urban population in the Amazon faces extreme levels of temperature and humidity in comparison with people living in other regions in Brazil, and small changes in the climatic conditions can make the difference in the decision to migrate. In addition, deforestation and rising temperatures have also been related to the incidence of tropical diseases in the region, such as dengue fever and malaria, which may also affect migration flows. A limitation of this analysis is the lack of individual-level information on the reasons of migration. Qualitative research based on in-depth interviews would reinforce the idea that migration is being mainly driven by environmental concerns and quality of life.

The study provides important elements to discuss the relation between environment and population dynamics in the Amazon. First, environmental change does matter for migration flows. This may be especially true among those who cannot afford the costs of mitigation or adaptation. Nonetheless, environmental factors are still neither the sole nor the most important to understand out-migration. Regional inequalities continue to play a central role, especially the best opportunities of employment and income that are still strongly concentrated in scarce areas in Brazil. However, the role of environmental change in migration flows within and to and from the Brazilian Amazon deserves further study given the negative prospects of the results stemming from climate change, on the one hand, and from the evolution of Amazonian society in the long run, on the other.

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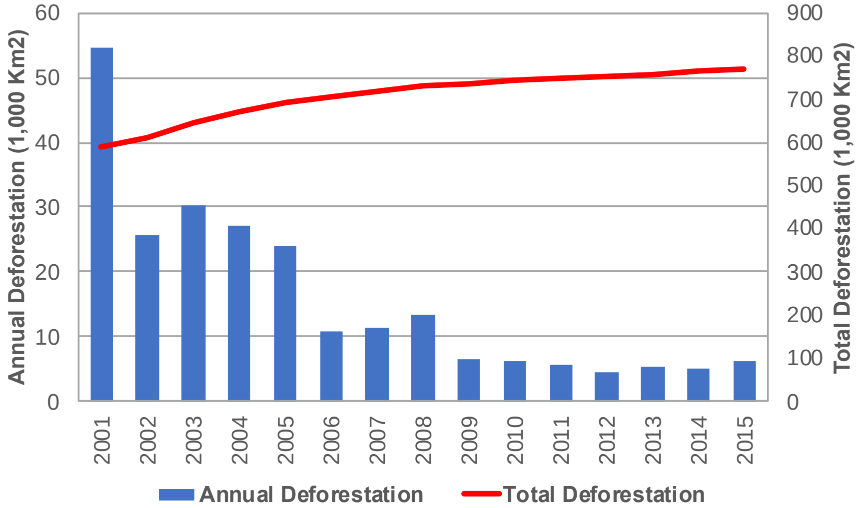
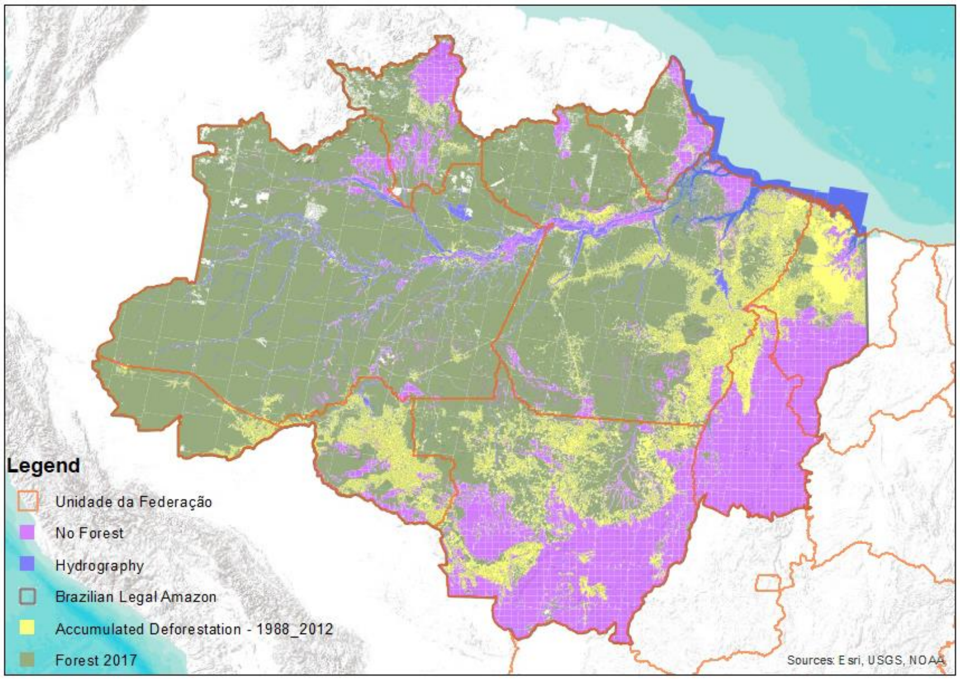
Figure 1 – Annual and total deforestation in the Brazilian Amazon



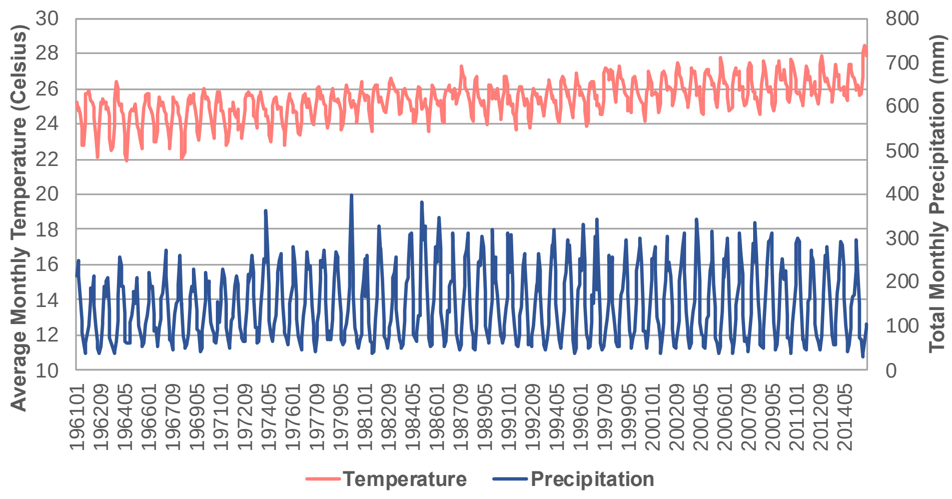
Source: PRODES, INPE

Map 1 – Land use in the Brazilian Amazon



Source: PRODES, INPE

Figure 2 – Monthly average temperature and total precipitation, Brazilian Amazon



Source: INMET and ANA

Table 1 – Total number of out-migrants, Brazilian Amazon

Variable	Description	Sum	Min	Max
Total migration	Number of out-migrants in the Amazon region between 2005 and 2010	1,503,873	0	17,202
Rural/urban classification				
Rural-rural	Number of migrants from rural origins to rural destinations	128,694	0	528
Rural-urban	Number of migrants from rural origins to urban destinations	297,946	0	1,386
Urban-rural	Number of migrants from rural origins to urban destinations	222,287	0	1,169
Urban-urban	Number of migrants from urban origins to urban destinations	854,946	0	17,202
Intra and inter-regional classification				
Intra-regional	Number of out-migrants who remained in the Amazon region	1,172,833	0	17,202
Inter-regional	Number of out-migrants who left the Amazon region	331,040	0	3,282

Source: Elaborated by authors using data from IBGE

Table 2 –Socioeconomic and environmental variables, Brazilian Amazon, Brazil

Variable	Description	Avg	Min	Max
Socioeconomic (control) variables				
Population size	Number of inhabitants in the municipality	19,674	674	1,114,834
Per capita Income	Monthly household per capita income (R$)	442	158	3,242
Employment rate	Ratio between the employed population and the working age population	0.554	0.296	0.741
Share agriculture	Share of agricultural workers in the employed population	0.442	0.016	0.779
Distance	Distance (km) between origin and destination	1,779	2	4,295
Environmental (interest) variables				
Deforestation	Increases in the share of deforested area between 2000 and 2005	0.070	0.000	0.979
Temperature growth	Linear trend for the average monthly temperature between 2000 and 2010 (ºC per month)	0.003	-0.005	0.009
Temperature extreme –	Number of months with average temperature below average value – 2se between 2000 and 2010	2.513	0	6
Temperature extreme +	Number of months with average temperature above expected value + 2se	2.263	0	5
Precipitation growth	Linear trend for total monthly precipitation (mm per month)	0.008	-2.039	1.508
Precipitation extreme –	Number of months with total precipitation bellow expected value – 2se	1.902	0	6
Precipitation extreme +	Number of months with total precipitation above expected value + 2se	4.385	1	9

Source: Elaborated by authors using data from IBGE, INMET and INPE

Table 3 – Estimates of the ZINB model for all types of migration flows, Brazilian Amazon

Variable	Beta	s.e.	p
Socioeconomic variables			
log Population size - Origin	0.256	0.007	***
log Population size - Destination	0.438	0.006	***
log Per capita Income - Origin	0.086	0.033	*
log Per capita Income - Destination	0.226	0.029	***
Employment rate - Origin	0.273	0.067	***
Employment rate - Destination	-0.048	0.055	
Share agriculture - Origin	-0.222	0.132	+
Share agriculture - Destination	0.843	0.122	***
Distance	-0.001	0.000	***
Environmental (interest) variables			
Deforestation	0.220	0.049	***
Temperature growth	7.922	3.851	*
Temperature extreme -	-0.023	0.006	***
Temperature extreme +	-0.008	0.006	
Precipitation growth	0.008	0.018	
Precipitation extreme -	-0.001	0.005	
Precipitation extreme +	-0.005	0.004	
Fixed Effects			
FUs origin	yes		
FUs destination	yes		
Overdispersion coefficient (k)	1.017	0.009	***
Total number observations	4,101,225		
Number zero observations	4,062,070		

Source: Elaborated by authors using data from IBGE, INMET and INPE

Table 4 – Estimates of the ZINB model for urban/rural migration flows, Brazilian Amazon

Variable	Rural-Rural			Rural-Urban			Urban-Rural			Urban-Urban		
	Beta	s.e.	p	Beta	s.e.	p	Beta	s.e.	p	Beta	s.e.	p
Socioeconomic variables	yes			yes			yes			yes		
Distance	yes			yes			yes			yes		
Environmental variables												
Deforestation	0.175	0.140		0.173	0.098	+	0.185	0.107	+	0.295	0.075	***
Temperature growth	5.018	8.934		-11.016	9.144		25.436	7.629	**	5.749	6.798	
Temperature extreme -	0.018	0.013		0.007	0.013		-0.020	0.012	+	-0.057	0.010	***
Temperature extreme +	-0.021	0.013		0.001	0.012		0.026	0.012	*	-0.028	0.010	**
Precipitation growth	0.024	0.053		0.033	0.044		-0.027	0.037		0.103	0.028	***
Precipitation extreme -	0.001	0.012		-0.004	0.011		-0.016	0.010		0.010	0.008	
Precipitation extreme +	-0.003	0.009		-0.024	0.008	**	0.014	0.010		-0.003	0.008	
Fixed Effects												
FUs origin	yes			yes			yes			yes		
FUs destination	yes			yes			yes			yes		
Overdispersion coefficient (*k*)	0.962	0.023	***	0.835	0.016	***	0.982	0.020	***	1.037	0.014	***
Total number observations	1,411,883			828,652			1,172,860			687,830		
Number zero observations	1,405,061			821,253			1,163,340			672,416		

Source: Elaborated by authors using data from IBGE, INMET and INPE

Table 5 – Estimates of the ZINB model for intra- and inter-regional migration flows, Brazilian Amazon

Variable	Intra-Regional			Inter-Regional		
	Beta	s.e.	p	Beta	s.e.	p
Socioeconomic variables	yes			yes		
Distance	yes			yes		
Environmental variables						
Deforestation	0.090	0.059		0.138	0.070	*
Temperature growth	-5.384	4.915		12.689	4.807	**
Temperature extreme -	-0.033	0.007	***	-0.020	0.008	*
Temperature extreme +	-0.024	0.007	**	0.013	0.008	
Precipitation growth	-0.040	0.023	+	0.094	0.028	**
Precipitation extreme -	0.000	0.006		0.009	0.007	
Precipitation extreme +	0.002	0.005		-0.006	0.006	
Fixed Effects						
FUs origin	yes			yes		
FUs destination	yes			yes		
Overdispersion coefficient (*k*)	1.030	0.011	***	0.591	0.009	***
Total number observations	562,475			3,538,750		
Number zero observations	536,700			3,525,370		

Source: Elaborated by authors using data from IBGE, INMET and INPE